Method for the preparation of a starch-containing product in particle form, a product obtained by the method and use of the same

The invention relates to a method for preparing a starch-containing product in particle form. The invention further relates to a product that can be prepared by the method in question, and to the use of the product.

Flour containing starch, such as the flour ground from cereal grains, is used in cooking both as raw material or semi-finished products in industrial production processes in the food industry in particular. There are problems in treating such flour, which to a large extent result from its fineness. Accordingly, the interaction of the particles and their tendency to adhere to surrounding surfaces make their handling in mass transfer difficult. If there are size differences between the flour particles, the different size particles have a tendency to separate from each other during transport and treatment. The treatment of fine flour is further impeded by its pulverable nature, causing health hazards and the danger of explosion. Furthermore, fine-grained flour is characterized in its slow silting in water, which is due to the large total area of the particles.

Another source of problems of starch-containing flour is the fat it contains. After grinding, the fat inherently contained by cereal grains remains, in the form of small globules, on the surfaces of the starch granules or the other components of the flour, and there is fat also inside the starch granules. In that case, the fat globules are in free contact with the air, whereby they can oxidize causing the flour to become rancid.

The problems with fat relate to oats in particular, the endosperm portions of its grains, which constitute the main part of oat meal, having a high fat content, about 6-8%. In addition to oxidation, such a great amount of fat has a hydrophobic effect, which for its part makes the elutriation of the flour difficult. Furthermore, the grain size of avenaceous starch is small, which makes the oat flour especially adhesive and agglomerative and, therefore, poorly running and difficult to dose.

It is well known to roll oat grains with the aid of heat and moistening so as to form flakes, whereby their processability is improved. The treatment has no considerable effect on the starch particles contained in the grains (Yiu et al, Can. Food Microstruct. (1986), 5(2), 219-225).

It is also well known to press starch-containing powdery materials so as to form pellets that are used as animal feed. In the process, material particles are bound to

each other mechanically under the effect of pressure. Neither does this process have considerable effect on the starch granules.

It is further known that starch granules swell and gelatinise under the effect of hot water, in which connection some ingredients of the starch; amylose and amylopectin are released from the damaged granules. In the literature, a manufacturing method of pellets intended to be used as animal feed is described, wherein water is used to damage the starch with the intent of providing a product that is quicker to digest (Thomas et al., Journal of the Science of Food and Agriculture (1999), 79(11), 1481-1494). It is also known to damage starch by extruding starch-containing flour, to which water has been added (Case et al., Cereal Chem. (1992), 69(4), 401-404). The degree of damage to the starch in the extrusion process was 20 to 100%.

The purpose of this invention is to provide a solution that removes the above problems of starch-containing flour regarding mass transfer, pulverization and silting, and which further essentially decreases the tendency of a material containing starch to become rancid because of fat oxidation. The manufacturing method of starch-containing products according to the invention is characterized in that the material containing starch granules and lipids is moistened, that the material is treated so as to damage the starch granules and to partly release their amylose and amylopectin so that lipids are bound to them, that the plastic mass obtained by the treatment, wherein the damaged starch acts as a binding agent, is dried and that the dried mass is broken down in particles.

The invention is, first, based on the partial release of amylose and amylopectin from the damaged starch granules so that, in the material, which was dried and thereafter mechanically broken down in particles, they act as a binder that keeps the particles together. Second, the invention is based on the observation that when starch granules are damaged, the lipids contained by the material are bound to the released starch so as to form a complex that protects them against oxidation. The preservability of the particle-form product obtained is thus considerably better than that of the starting material, wherein there is free fat on the surfaces of the starch granules or the other ingredients. At the same time, the bonding of fat decreases the hydrophobicity of the product caused by the fat, for its part facilitating the silting of the product in water.

In the invention, any problems caused by the fineness of the starch-containing flour are solved by, at the final stage of the process, mechanically breaking down in particles the dried mass bound by the starch, the size of the particles being freely selectable. The end product can thus be essentially coarser than the flour that was the

initial material, whereby the product is easier to handle, transfer and dose, it silts quicker, its moisture resistance is better and it is less pulverulent. Whereas the particle size of flour ground from cereal grains is typically less than 0.25 mm, the invention may consist of a granulation of flour, wherein the size of the end product granules is in a range of 0.25 – 2.0 mm. The granules can be obtained from dried mass by grinding, whereby the granule size can be adjusted by means of grinding and, as necessary, by grain size analyses so as to remove any oversized and/or undersized granules from the end product.

On the other hand, the initial material of the process according to the invention may not necessarily have to be powdery, but unmilled grains or starch-containing material can also be used, the latter having been rendered the shape of flakes, pellets or tablets, e.g., by pressing, and still having whole starch granules left. Various extruded pieces silt up and decompose when wetted, after which they are processed in the same manner as when starting with a powdery starting material so as to obtain an end product according to the invention.

The optimal level of moisture content, to which the material comprising the initial material is moistened, is according to the invention about 21 – 26%. Correspondingly, the amount of energy consumption in damaging the starch is optimally 22 – 30 kWh / 1000 kg of material, calculated according to the dry weight. With these parameters, partial damage to the starch granules is obtained, resulting in a plastic mass that binds essentially all the fat present, and that can be dried and ground so as to form particles that are easy to process and silt.

According to the invention, the method for damaging the starch granules can vary. The form of energy exerted on the granules can be heat, pressure, shearing forces, mechanical energy or a combination thereof. If the material is heated in connection with moistening, damage to the starch is achieved which, however, is not sufficient from the point of view of the invention. Advantageous techniques according to the invention include, in particular, leading the moistened material through and extruder or an expander. The process as such increases the temperature of the material, in addition to which extra heat can be lead into the material. Other alternatives include, among others, processing the material in a pressure vessel or an autoclave. According to observations, the maximum temperature, to which the material can be brought in connection with the process without impairing the results, is 105°C.

The degree of damage to the starch resulting from the partial damage to the starch granules according to the invention is preferably about 30 – 60%. Further damage to the granule does not improve the end product but may rather impair the same. The degree of damage refers to the release of amylose and amylopectin, whereby on a

degree of damage of 100%, all starch granules are broken so that the said components are in full contact with the surrounding phase. When the degree of damage is less than 100%, different granules can have different kinds of damages, and part of the granules can even be undamaged. It is preferable that some whole starch granules remain a part of the end product, as the granules increase the porosity of the product and can thus improve its water absorbency.

Because of the high fat content of oat grains, the invention is especially advantageous in the preparation of a product that contains avenaceous starch. In that case, the initial material of the process can be oat meal, whose starch content is at least about 50%, preferably about 70 – 90%, and the fat content about 5 – 8%. Unmilled oat grains or whole, non-gelatinized avenaceous starch granules that are separated from the grains can also be used as initial material. It is further possible that the initial material is a mixture having avenaceous starch or oat meal combined with some other desired ingredient of the end product. The latter is preferably already in the form of particles, but it can also be, in the damaging process of the starch grains, such as moistening and the following extrusion, decomposable into a fine-grained form so that a homogeneous plastic mass is obtained as the end result.

Within the invention, it is also possible that fat is added to the starch-containing material that is to be processed, which fat at least partially is bound to the damaged starch. In this way, the fat content of the end product can be increased and, nonetheless, a product with a good preservability can be provided. This can be utilized in products that are based, for example, on wheat starch and whose natural fat content is low.

The starch-containing, particle-form product according to the invention, which can be prepared in accordance with the above, is characterized in containing damaged starch, wherein the amylose and amylopectin of the starch granules are partially released, while the starch acts as a binder keeping the particles together, as well as lipids bound by the starch in an amount of at least 2% of that of the starch. Furthermore, the invention covers any corresponding products, wherein the lipids in total are essentially bound in a complex manner.

In the preferred applications of the product according to the invention, the degree of damage to the starch granules is 30 – 60%, the product still has some whole starch granules that were not damaged in the process, the starch content of the product is at least 50% and the fat content of the product is at least 1%. The fat content may be based on the fat inherently contained in wheat grains, or the fat can be separately added to the product during its preparation process.

The complex bonding of the lipids contained in the product, such as fats, with the amylose and amylopectin of the starch or with the other ingredients of the product can be defined by means of DSC measurement (Differential Scanning Calorimetry). If there is free fat present in the product, it is visible in the DSC graph as an endothermic melting peak of fat, i.e., the product according to the invention is characterized in the lack of the peak in the graph. Bonding of fat in the process according to the invention can be observed when comparing with the DSC graph of the initial material, wherein the presence of free unbound fat is visible as the said melting peak. Instead, a peak resulting from the complex of starch and fat appears in the graph of the end product at a higher temperature.

Correspondingly, DSC measurements can be used to measure the degree of damage to the starch granules in the process. When the material is heated, the gelatinisation of the starch is shown as a peak on the DSC graph. The gelatinisation peak of the graph obtained from the product decreases along with an increase in the degree of damage to the starch. If the damage to the starch according to the invention is partial, the gelatinisation peak of undamaged starch is visible, even though it is lower compared with the initial material. The gelatinisation peak will not disappear until the starch contained by the product is completely damaged. Such a product, wherein the starch is fully gelatinised, is not included within the invention.

The product according to the invention is preferably granular, the grain size mainly being within 0.25 – 2.0 mm. The final grain size and size distribution can be controlled by means of particle analyses. Preferable products comprise granulated oat meal or avenaceous starch in particular.

The invention further covers the use of the particle-form product prepared in accordance with the above description or presentation as foodstuff or an ingredient of foodstuffs in bakery products, for example.

The invention is illustrated in detail with the aid of the following examples that are based on laboratory testing.

Example 1. Granulation of oat meal and stabilization of fat by expansion

Oat meal obtained from peeled oat grains by means of mechanical distribution were used in the test. The flour contained 75% of starch, 11.5% of protein, 6.0% of fat, 6.0% of fibre and 2-0% of b-glucane. The moisture content of the flour was 8.8% and the specific weight 0.43 kg/dm^3.

The flour was prepared in batches of about 20 – 25 kg in a 100 l drum mixer. 9 – 10% of water of a moisture addition and 3 – 4% of vapour were lead into the mixer. The dwell time in the mixer was about 10 – 15 min, during which time the tempera-

ture increased to 80°C. The flour that was prepared in various ways was lowered into a tub, from where they were lifted onto the feeder of an expander. On the whole, 7 preparation operations were carried out, four of which in a moisture of 21% and three in a moisture of 26%.

The type of the expander was OE 8 and it had a screw that conveyed the heated, moist flour in a cylinder of about 1 m to the end thereof, wherein a counterpressure was provided because of a hydraulically adjustable, conical mouth piece that closed the end opening. The effect of pressure (18 – 80 bar) and the shearing effect with the flour drifting through a 0.1-0.2 mm slot formed by the cylinder and the mouth opening plasticized the flour so as to form a thin, firm, plate-like and plastic structure. The material was dried with a blast drier and ground with a mill provided with a cutting edge and a 2 mm sieve. In this way, a product was obtained which was fluid and, thus, easy to dose, and which lacked the adhesion to surfaces typical of oat meal.

Table 1 shows that part of the starch sets already during preliminary preparation and the degree of setting depends on the humidity prevailing in the preparation. In a humidity of 26%, over 90% of the starch of the flour is in a set state, and in a humidity of 21%, setting was minor. The setting enthalpies were defined by means of DSC in a moisture content of 70%.

Table 2 shows the process parameters used in the expansion for flour prepared in different moistures. When studying the setting enthalpies of the table, it can be observed that with parameters, on which the output temperature exceeded 105°C, the starch was fully damaged irrespective of whether the moisture in preliminary preparation had been 21 or 26%.

Table 3 indicates that the prefabrication and the following expansion in particular, at their best, more than triplicate the water retention capacity of the product. A positive correlation prevailed between the water retention capacity and the degree of setting. The water retention capacity was defined by weighing the amount of the water bound to the product, after metering 2.5 g of product and 30 ml of water into a centrifuge tube and gently agitating the mixture in a double boiler at 30°C for 30 minutes before separating the unbound water by a centrifugal treatment.

Table 4 illustrates the changes in the lipid balance and the lipid composition of the flour under the effect of prefabrication and the following expansion. The prefabrication reduces the amount of changing lipids, which is particularly obvious in a prefabrication carried out in a humidity of 26%. When the prepared flour is expanded, the amount of lipids further reduces and the reduction is at its greatest for such ex-

panded flour, wherein the starch had been fully damaged (cf. Table 2). Thus, it could be stated that the degree of damage and the reduction in the amount of lipids show a positive correlation. Relatively the most significant of the lipid class changes was the reduction of free fatty acids (FFA) upon the degree of damage increasing. Thus, the damage to starch in prefabrication and expansion reduces the amount of extractible free fatty acids in particular.

Lipid analyses were carried out by extracting both the prepared flour and the prepared and then expanded flour by means of a mixture of dichloromethane methanol (2:1), and by dividing the extracts into four lipid classes by means of thin layer chromatography: polar lipids (PL), triacyl glycerols (TG), diacyl glycerols (DG) and free fatty acids (FFA) (Liukkonen et al., *J Agric Food Chem* **40** (1992) 126 – 130). The lipid classes were defined by analysing from each lipid class the fatty acids as methyl esters by means of gas chromatography (Suutari et al, *J. Gen. Microbiol.* **136** (1990) 1469 – 1474).

Table 5 shows the amounts of hexanal that are released from the products, which are prepared by the methods described above, immediately and during accelerated aging on a light desk. It is discovered that there are no essential differences in the products prepared in different ways immediately after the preparation. Instead, as a result of light activation in products, wherein the final temperature of expansion exceeded 108°C, the hexanal responses elevated to an extremely high level. On the basis of the test, it is obvious that the desired preservability effects of fat are not achieved in expansion when using temperatures of more than 105°C.

In accelerated ageing, the samples are kept on a lighted glass plate of about 35°C for two weeks before the analysis of the amount of releasing hexanal. The amount of releasing hexanal was analysed by gas chromatography, to which a static Headspace sample feeder and a mass selective detector had been connected, as described in the reference Heinio, et al. *Cereal Chemistry* **79**(3) (2002) 367 – 375.

On the basis of the example, it can thus be stated that under prefabrication and expansion conditions, wherein partial setting of the starch takes place, the best preservability against the rancidness of fats is achieved.

Example 2. Extractibility of lipids in extruded oat meal

Oat meal in accordance with Example 1 was selected for extrusion. The extrusion was carried out at temperatures of 40, 60, 80, 100, 120 and 140°C. The extruder was Pompes DKM-Cletral BP-10. The flour was fed as such into the apparatus and water from a feed tube of its own to the screw. In the samples it was carried out, a fat

addition was performed adding rapeseed oil in a continuous string into a mixer. Table 6 shows the process parameters used in the extrusion.

The amount and the composition of lipids were defined from the oat meal and the extrusion products obtained from the same (Tables 7 and 8). In products that had been extruded within a temperature range of 40 to 80°C, the amount of extractible whole lipids decreased with respect to the non-processed flour. The amount of whole lipids at temperatures of over 100°C, in turn, was higher than that of the flour. The reduction in the amount of whole lipids resulted from the reduction of the amount of non-starch lipids. Correspondingly, the amount of starch lipids grew. Table 9 describes the redivision of the fat in the flour into starch and non-starch lipids in extrusions carried out at various temperatures. On the basis of the results (Tables 7, 8 and 9), it may thus be concluded that extrusion can be used to redirect non-starch lipids of flour into starch lipids. By adjusting the extrusion temperature to below 120°C, the amount of the whole lipids being measured (extracted) can also be decreased.

The lipids were defined by extracting with a mixture of n-propanol and water. The lipids were divided into starch and non-starch lipids by a known method (Morrison, W. R., Starch/Stärke 33, 1981, 408-410) by first treating the flour with a room temperature solvent so as to extract the non-starch lipids, and by treating the extract residue with a hot solvent to extract the starch lipids. The lipids were defined as fatty acids by gas chromatography, as previously described (Suutari *et al.*, 1990).

The numbers of damaged starch particles were defined from the products described in the examples in accordance with a method developed by VTT (the method identifier VTT-435591). Table 10 shows that pressing the flour into pellets had only caused very moderate damage to the particles. In extrusion, instead, the portion of damaged starch increased crucially. The degree of damage grew with the extrusion temperature growing, illustrating the discharge of the composition that took place when the particles set.

Example 3. Distribution of fat added to the oat meal in extrusion

5% by weight of fat (DIVA rapeseed oil) were added to the oat meal according to Example 1, mixing with a universal mixer. The mixtures of flour and fat were extruded, as described in Example 2. Extracting total fat, non-starch lipids and starch lipids were defined from the products in the way described in Example 2.

Table 11 shows that not even at one of the temperatures used did the amount of total fat extracted from the extrusion products correspond to the total amount of added fat and the fat contained in the flour itself.

The extrusions increased the amount of starch lipids with respect to the non-extruded flour. The increase was proportional to the temperature used. When extruding the mixtures of flour and fat, the amount of starch lipids grew with respect to the untreated flour at all temperatures used. At temperatures of 60, 80 and 100°C, part of the added fat were extracted as starch lipids. Thus, it could be concluded that in the extrusion process, the oat meal according to Examples 1 and 2 binds the fat mixed with it and forms starch lipids.

Example 4. Effect of extrusion temperature on the preservability of the fats in oat meal

Oat meal was extruded using the running parameters described in the invention and repeating the test in an identical way but at a higher temperature. Non heat-treated oat grains (the species Roope) that were peeled for the test were ground with a laboratory mill (Frisch pulverisette 14) immediately before extrusion (an APF-MPF 19/25 laboratory extruder). Flour was fed onto the extruder screw at a velocity of 25 g/min and water at 20 ml/min. The screw temperature was adjusted to 105°C or 130°C. The extrusion products were allowed to cool down for 24 hours at +20°C, after which they were liophilicized and reground with the laboratory mill.

The bonding of fats was defined by extracting at room temperature the unbound fats from the extrusion products by means of a mixture containing n-propanol and water in a ratio of 2:1 (Morrison, 1981). The total amount of fatty acids were measured from the extract by gas chromatography (Suutari et al. 1990), and the amount of bound fat was obtained by subtracting the amount of extracted fat from the total fatty acid content of the flour obtained by the same method. Table 12 indicates that 55 – 62% of the fats in the oat meal were bound in extrusion, and that the amount of bound fat after extrusion was 91 – 111% greater than that of untreated oat meal.

The test also indicates that rancidity in whole meal extracted at 105°C is slower compared with untreated whole meal, and that flour extruded at 130°C became rancid faster, although bonding was even stronger.

Example 5. Bonding of linolic acid to gelatinised starch

According to Examples 1 to 3, in processes, wherein damage to starch occurs, the portion of starch lipids from the whole lipids of the flour grows. At the same time, the preservability of fat against rancidness is enhanced.

When avenaceous starch is heated in a 30% water suspension to 50°C or 53°C, part of the starch is damaged, which is indicated by the setting enthalpies of starch, which are defined by means of calorimetry and shown in Table 13. The table shows

that partly damaged starch protects the lipids, which oxidize easily, considerably more effectively than a corresponding undamaged starch.

For the test, 100 mg of starch was mixed with 7 ml of a 0.2 M na-phosphate buffer, pH 7.0. 0.3 ml of miscellated linolic acid was added to this so that the amount of the added free linolic acid was 0.87 mg (Axelrod, et al., in the work: Methods in entzymology vol 71; Lowenstein, J.M., Ed.; Academic press: New York, USA, 1981.). The mixture was mixed for 100 s; whereafter 0.1 ml of lipoxygenase solution was added to it (1 mg/ml, Sigma L-8383). The oxygen consumed by the mixture was followed by means of polarography, and the time spent by the amount of dissolved oxygen to decrease to 54 µmol was written down.

If the starch is completely damaged, as in the commercial product Remy F6-P (precooked rice starch), the prevention of oxidation was even more efficient, cf. Table 14. Thus, the degree of damage to the starch is clearly connected with the oxidation of linolic acid.

Example 6. Use of extruded oat meal in baking

Oat meal granulated by the method according to Example 1 (total energy 25 kWh/t, temperature 105°C) and the flours mentioned below were compounded with wheat flour (the Paakari semicoarse wheat flour, Avena Oy) and the water retention of the compounded flours was defined. The flours used for compounding and their amounts in the wheat flour were as follows:

Oat meal A (Oat flour 1, 143B2J11, Avena Oy), 10%
Oat meal B (Extruded oat flour A), 5%
Oat meal B, 10%
Oat flakes (Elovena, Melia Oy), 10%
Potato flakes (Norrgard), 5%

The water retention was defined by metering 2.5 g of the flour mixture into a large centrifuge tube, and by adding 30 ml of water. The mixtures were incubated in a water bath to 30°C for 30 minutes, agitating at intervals. Unbound water was separated by centrifugation and the amount of water bound to the sample was obtained by weighing. The dry weight of the flour mixture was taken into consideration when calculating the results of water retention shown in Table 15.

Table 16 indicates that the oat meal prepared in accordance with the invention improves the water retention of wheat flour even in a 5% portion of the mixture. Similarly, it appears that treating oat meal according to the invention, when mixed with wheat flour, improves the water retention of the mixture compared with untreated

oat meal. It is further apparent that the water retention is more effective than in wheat flour compounded with oat flakes. Generally, potato flakes are used in baking to improve water retention. The table shows that, when processed in accordance with the invention, oat meal provides almost equally effective water retention.

Farinography characterization of corresponding mixtures further shows that adding oat meal B to wheat flour enhances the water retention of the wheat flour, and the enhancement may even be slightly higher than that of oat bran, approaching the effect provided by potato flakes. When studying the dough forming time, it can be discovered that, unlike the oat flakes and potato flakes involved in the comparison, oat meal does not increase the forming time.

Tables

Table 1. Setting enthalpies of the starches of oat meal and prepared oat meal, and peak temperatures of gelatinisation

Sample	**ΔH (J/g)**	**Peak temperature of gelatinisation (°C)**
Oat meal	-7.31	59.8
Prepared flour, moisture 21%	-5.45	60.2
Prepared flour, moisture 26%	-0.53	69.7

Table 2. Running parameters of the expander process

Sample	Capacity (kg/h)	Supply frequency (Hz)	Motor power (kW)	Energy consumption (kWh/t)	Pressure (bar)	T_{out} (°C)	ΔH (J/g)
Oat meal							-7.31
Expanded flour 1 (moisture 21.8%)	86	15	2.5	22.2	35	95	-1.6
Expanded flour 2 (moisture 21.4%)	92	15	3.4	30.4	55	105	-0.71
Expanded flour 3 (moisture 21.6%)	242	50	5.0	18.2	70	108	0
Expanded flour 4 (moisture 21.8%)	270	50	6.5	22.6	80	105	-0.91
Expanded flour 5 (moisture 26.0%)	381	50	6.3	14.9	70	105	-0.62
Expanded flour 6 (moisture 21.7%)	156	40	5.5	31.4	105	120	0
Expanded lour 7 (moisture 21.1%)	144	32	5.8	36.1	105	130	0

Table 3. Water retention of oat meal, prepared oat meal and expanded oat

Sample	Water retention (g of water/g of dry flour)	Water retention compared with original flour
Oat meal	1.15	
Prepared flour, moisture 21%	1.43	1.2x
Prepared flour, moisture 26%	2.25	2.0x
Expanded flour 1	2.84	2.5x
Expanded flour 2	3.32	2.9x
Expanded flour 3	3.77	3.3x
Expanded flour 4	3.11	2.7x
Expanded flour 5	3.13	2.7x
Expanded flour 6	3.80	3.3x
Expanded flour 7	4.29	3.7x

Table 4. Lipid class compositions of oat meal, prepared oat meal and expanded oat meal

Sample	Total lipid content (mg/g)	PL (%)	TG (%)	DG (%)	FFA (%)
Oat meal	72	18	67	6	9
Prepared flour, moisture 21%	70	18	68	6	8
Prepared flour, moisture 26%	64	18	73	6	2
Expanded flour 1	62	17	72	6	4
Expanded flour 2	58	17	72	6	5
Expanded flour 3	52	16	74	6	4
Expanded flour 4	64	16	75	6	3
Expanded flour 5	63	16	74	6	4
Expanded flour 6	54	16	72	6	5
Expanded flour 7	40	17	72	6	5

Table 5. Hexanal responses of oat meal, prepared oat meal and expanded oat meal

Sample	Hexanal response	Hexanal response after storing on light table
Oat meal	0.4	3.3
Prepared flour, moisture 21%	0.6	4.0
Expanded flour 1	0.4	3.5
Expanded flour 2	0.2	13.5
Expanded flour 3	0.5	91.9
Expanded flour 4	0.4	5.0
Expanded flour 5	0.3	7.5
Expanded flour 6	0.5	206.4
Expanded flour 7	0.6	252.0

Table 6. Running parameters of extruder process

Sample	Water supply	Temperature (°C)	Torsion (mN)	Rotation speed of screw (rpm)	Power (A)	Feeding velocity of flour (rpm)
Extruded flour 1	0.4	40	23.4	301	2.34	22
Extruded flour 2	0.4	60	19.6	304	1.88	22
Extruded flour 3	0.4	80	17.7	304	1.71	23
Extruded flour 4	0.4	100	15.2	302	1.48	23
Extruded flour 5	0.4	120	15.5	305	1.51	22
Extruded flour 6	0.4	140	14.4	301	1.42	22

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Table 7. Amount and composition of non-starch lipids of oat meal and extruded oat meal

Sample	Total lipid content (mg/g)	C16:0 (%)	C18:0 (%)	C18:1 (%)	C18:2 (%)	C18:3 (%)
Oat meal	59.2	17	2	36	43	2
Extruded flour 1	32.6	17	2	36	43	2
Extruded flour 2	30.8	17	2	37	43	2
Extruded flour 3	27.0	17	1	37	43	1
Extruded flour 4	35.2	17	1	38	43	1
Extruded flour 5	37.4	17	2	35	44	2
Extruded flour 6	25.7	18	2	35	44	2

Table 8. Amount and composition of internal lipids of starch of oat meal and extruded oat meal

Sample	Total lipid content (mg/g)	C16:0 (%)	C18:0 (%)	C18:1 (%)	C18:2 (%)	C18:3 (%)
Oat meal	7.3	37	1	22	38	1
Extruded flour 1	21.2	22	1	32	43	1
Extruded flour 2	26.6	21	1	32	45	2
Extruded flour 3	30.9	21	1	33	44	1
Extruded flour 4	32.7	21	1	31	46	1
Extruded flour 5	41.0	21	1	33	42	1
Extruded flour 6	51.8	21	1	33	43	2

Table 9. Portions of non-starch lipids and internal lipids of starch from the whole lipids of oat meal and extruded oat meal

Sample	Portion of non-starch lipids (%)	Portion of internal lipids of starch (%)
Oat meal	89	11
Extruded flour 1	61	39
Extruded flour 2	54	46
Extruded flour 3	47	53
Extruded flour 4	52	48
Extruded flour 5	48	52
Extruded flour 6	33	67

Table 10. Portion of damaged starch in oat meal, pellets pressed from oat meal and extruded oat meal

Sample	Damaged starch (%)
Oat meal	3.3
Oat meal pellet	5.2
Extruded flour 1	27.5
Extruded flour 2	28.7
Extruded flour 3	31.3
Extruded flour 4	44.4
Extruded flour 5	45.5
Extruded flour 6	44.5

Table 11. Amounts of extractible whole fat and portions of non-starch lipids and internal lipids of starch in extruded oat meal samples, whereto 5% of fat were added

Sample	Total lipid content (mg/g)	Portion of non-starch lipids (%)	Portion of internal lipids of starch (%)
Oat meal	66.5	89	11
Extruded flour with a 5% addition of fat 1	98.5	85	15
Extruded flour with a 5% addition of fat 2	122.7	48	52
Extruded flour with a 5% addition of fat 3	107.5	65	35
Extruded flour with a 5% addition of fat 4	109,0	54	46
Extruded flour with a 5% addition of fat 5	97.1	76	24
Extruded flour with a 5% addition of fat 6	89.4	81	19

Table 12. Binding of fats of oat meal in extrusions. Amounts of fatty acids mg/g of flour

	Untreated oat meal	Extruded oat meal	
		105°C	130°C
Bound fat	20 mg/g	38 mg/g	42 mg/g
Non-bound fat	47 mg/g	30 mg/g	26 mg/g

Table 13. Effect of damage to avenaceous starch on capacity of starch to protect easily oxidable lipids against becoming rancid

Treatment temperature	Setting enthalpy (J/g)	Oxidation speed*
No treatment	7.6	27 min 56 sec
50 C	7.4	-
53 C	5.9	1 h 20 min

*The time needed for decreasing the amount of dissolved oxygen to 54 µmol in a 1.4% starch suspension. Linolic acid and lipoxygenase enzyme that oxidizes linolic acid were added to the suspension.

Table 14. Effect of damage to rice starch on the ability of starch to protect easily oxidable lipids against becoming rancid

Treatment	**Oxidation speed***
Native rice starch (Remy B7)	6 min 36 sec
Precooked rice starch (Remy F6-P)	43 h

*The time needed for decreasing the amount of dissolved oxygen to 54 µmol in a 1.4% starch suspension. Linolic acid and lipoxygenase enzyme that oxidizes linolic acid was added to the suspension.

Table 15. Water retention of flour mixtures

Flour		**Water retention, g of water/dry sample**
Wheat flour		1.2
"	+ 10% of oat meal A	1.1
"	+ 5% of oat meal B	1.3
"	+ 10% of oat meal B	1.3
"	+ 10% of oat flakes	1.2
"	+ 5% of potato flakes	1.4

Table 16. Water retention capacities measured by means of farinography, and forming times

Sample	**Water retention, %**	**Forming time, min**
Wheat flour	60.0	2.25
" + oat meal A	60.4	1.5
" + oat meal B, 5%	62.5	2.25
" + oat meal B, 10%	65.5	2.0
" + oat bran, 10%	62.4	7.0
" + potato flakes, 5%	67.5	3.0